GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 10/7/80

Project Title: PRODUCTION AND DISTRIBUTION RESEARCH CENTER

Project No: E-24-621

Project Director: DR. H.D. RATLIFF

Sponsor: OFFICE OF NAVAL RESEARCH, ARLINGTON, VA 22217

Agreement Period: From 7/1/80 Until ~~9/30/82~~ 11/30/82 (PERF. PERIOD)

Type Agreement: SFRC NO. N00014-80-K-0709

Amount: $438,624 ONR (PARTIALLY FUNDED FOR $69,098 THRU 9/30/80)
42,000 GIT/E-24-345 (PARTIALLY FUNDED FOR $7,000 THRU 9/30/80)
$480,624 TOTAL

Reports Required: ANNUAL LETTER REPORT; FINAL TECHNICAL REPORT

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GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

Date 11/1/82

Project Title: Production & Distribution Research Center

Project No: E-24-621

Project Director: Dr. H. D. Ratliff

Sponsor: ONR

Effective Termination Date: 11/30/82

Clearance of Accounting Charges: 1/31/83

Grant/Contract Closeout Actions Remaining:

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- [ ] Final Fiscal Report
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E24-621

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PRODUCTION and DISTRIBUTION RESEARCH CENTER

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A UNIT OF THE UNIVERSITY SYSTEM
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ANNUAL
PROGRESS REPORT
PRODUCTION AND DISTRIBUTION
RESEARCH CENTER

SEPTEMBER 28, 1982

submitted by

H. DONALD RATLIFF
Center Director

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I. INTRODUCTION

Problems associated with producing, storing, and distributing products and materials are fundamental to the military. They have motivated much of the work in Industrial Engineering, Operations Research and more recently in Computer Science. The increasing role of machinery and equipment over the years has caused a shift of primary focus from a concentration on work methods to a concentration on the design and operation of integrated systems of people and equipment. The advent of computers has dramatically increased the potential for designing, analyzing, measuring, and controlling these systems.

It is interesting to note that in the past very little of the research devoted to production and distribution has been directed toward the understanding or solution of the kinds of problems actually faced by practitioners. The research effort has primarily concentrated on developing mathematics for solving (a) very general models such as integer programming which, if efficiently solvable, would allow us to better solve many of the production and distribution problems and (b) very limited abstractions of the actual problems, such as the single machine scheduling problems, which could hopefully be generalized to more realistic situations.

Given the recent results relating the complexity of combinatorial problems, one would have to be extremely optimistic to believe that efficient solution methods for general integer programs can be developed or that results such as those for single machine scheduling can be extended to realistic problems. One must conclude that these traditional research areas do not seem very promising in terms of developing better approaches for attacking the actual problems in production and distribution.

with designing and operating production and distribution systems in order to better define and understand the problem areas, (2) to set priorities for research, and (3) to initiate a broad program of research in the areas of highest priority.

The following sections describe the problem areas identified, the research approach and research results. Appendices list Center research reports, visits to Navy and related installations, presentations by Center personnel and visitors to the Center.

While developing mathematical models in the abstract continues to expand the tools we have to draw on, this is not enough. A fundamental refocusing of research in production and distribution is required. This should include: (a) primary concentration on the significant problems actually faced by practitioners (b) development of mathematical structures that enhance our insight into the problems themselves, and (c) development of models and methodology which can interface with people to generate solutions to these problems.

The Production/Distribution Research Center was established in July 1980 to address these needs. The Center has become an important part of the developing rapport among private industry, governmental and military institutions, and the academic community. The School of Industrial and Systems Engineering (ISyE) at Georgia Tech houses the Center, whose primary originating funding source has been the Office of Naval Research (ONR). This funding permitted the establishment of the Center and supports its continuing development. Seven faculty members and 10 graduate students currently pursue basic research related to understanding and improving fundamental processes in production and distribution.

<u>Long Range Scientific Objectives</u>: The Production/Distribution Research Center was established to accomplish three basic objectives: 1) to expand our knowledge of the fundamental problems associated with designing and operating Navy-related production and distribution systems, (2) to develop new methodologies which can be used to improve these processes, and (3) to provide a focal point for research in these areas.

<u>Project Objectives</u>: The major goals for the first two years of the project were: (1) to establish contacts with military and civilian groups involved

II. PROBLEM AREAS

Research in the Production and Distribution Research Center addresses basic questions associated with the configuration, operation, and assessment of manufacturing systems, storage systems, and delivery systems. The research is concentrated on problems related to movement and placement of people and material. Because of the need to understand operational issues before addressing the areas of configuration and assessment, most of the research to date has focused on operations. However, quantitative methodology may ultimately have its greatest impact in system configuration.

System Configuration. Fundamental issues include: how to relate system objectives to design criteria; how to break the system into components; how to interface the components with each other; how to determine and assess the impact of acquisition strategy; how to size the system; how to select equipment; and how to lay out the components of the system.

System Operation. Fundamental issues include: how to position units to facilitate movement; how to group units for combined transportation; how to route vehicles; how to schedule resources; and how to develop system discipline.

System Assessment. Fundamental issues include: how to predict requirements; how to predict capability; how to measure performance in terms of requirements and capability; and how to structure, validate, maintain, and present information system data.

While the fundamental issues regarding placement and measurement of people and material are essentially the same in manufacturing, storage, and delivery systems, the specific problems vary widely depending on context.

For example, the problem of slotting material in a warehouse and of prepositioning forces for rapid deployment both involve the issue of positioning units to facilitate movement. However, because of their contexts, the two problems are radically different. Since there is such a wide variety of problem contexts, the number of problems associated with the fundamental issues above is virtually limitless. A premise underlying the Center is that the commonality of issues will ultimately lead to unifying approaches for addressing these problems.

III. RESEARCH APPROACHES

Production/distribution systems are usually complex and not amenable to exact global solution. Accordingly, we invoke the following basic philosophy of problem-solving: partition the system into more tractable but natural subproblems, develop solution techniques for the subproblems, and then develop methods of integrating subproblem solutions so that system-wide performance is enhanced. Frequently, the subproblems correspond to physical components of the system. For example, to increase the throughput of a warehouse, we are lead to consider subproblems related to increasing the throughput of individual component such as a carousel conveyor. Then we must consider how to increase the throughput of a system of carousel conveyors, and, beyond this, how to integrate systems of carousel conveyors into the overall functioning of the warehouse. Thus, as in this example, we build from effective control of component subsystems to effective control of the total system.

Some of the smaller problems are so tractable as to succumb to optimization techniques, which we develop as appropriate. Most problems, however, resist such solution. For these more difficult problems we invoke one of two general approaches, depending on the nature of the problem environment. Operating decisions tend to be made frequently and allow little time for reflection. For such problems we develop heuristics that require minimal computational effort, yet provide solutions of acceptable quality. This requires consideration of complexity, probabilistic analysis, and worst case analysis of decision techniques.

Design decisions tend to be made infrequently but have long term, expensive implications for system operation. Thus, in-depth analyses can be justified. For these problems the concept of "human aided optimization" seems the most promising. This concept involves underlying mathematical models (e.g., optimization, queueing, simulation), a computer graphics interface and a human decision maker. The human guides the process, utilizing primarily graphical information and makes the ultimate decisions. The models suggest and help evaluate alternatives based on input from the human decision maker. The research effort includes developing new models and solution techniques, analyzing the proper role of the human decision maker, and determining graphical interfaces which can provide the human with the necessary insight to guide the process.

IV. SUMMARY OF ACCOMPLISHMENTS TO DATE

Our major goals for the first phase of the Production/Distribution Research Center have been to establish priorities for research areas, to inititate a broad program of research, and to gain visibility for the Center within the Navy and in the private sector. We have also began to disseminate our research developments using a variety of approaches including technical reports, seminars, short courses, demonstrations, and visits with potential users.

Reports

Thirty three reports have been completed which describe faculty and student work in the PDRC. A list of reports published to date together with a brief abstract on each is given in Appendix A. The major thrust of the various research initiations are summarized in Section V. The accomplishments in these areas are an indication of the tremendous potential for research in production and distribution. We feel that we have established a solid base for a continuing research effort.

Interaction with Researchers/Practitioners in the Field

The PDRC has the potential to improve the interface between the experts who are shaping the modeling methods and algorithms and the decision makers in military, government and private industry who understand the situations these models address. This interchange of ideas is fostered through seminars, projects, visits and other exchanges for which PDRC is an effective focus. The Center, in bringing together faculty, students and practitioners, creates an atmosphere for development of practical directions in university research and promotes greater appreciation among practitioners for the applications of modeling and analysis.

We have established a wide range of contacts in the Navy and in private industry. Briefs, seminars, and visits by PDRC personnel at Navy installations are described in Appendix B. This interaction has allowed us to obtain input on significant research areas and to inform Navy personnel about the activities of the Center. We have found these visits to be extremely valuable as a part of our efforts to establish research priorities and to gain visibility for the PDRC.

PDRC members have also been active in presenting papers and briefs on PDRC activities to industry and at national meetings. A list of these presentations is given in Appendix C.

Over 300 managers and engineers have visited the PDRC for live demonstrations of our color graphics-based prototype systems for analyzing layout and distribution problems and formal discussions with PDRC personnel. A partial list of these visitors is given in Appendix D. Most of the visitors came as a result of personal contacts with PDRC personnel. Others came as a result of the three short courses given annually at Georgia Tech by members of the PDRC which directly relate to ongoing PDRC research activities. They are Material Handling (1982 keynote address by Rear Admiral Philip McGillivery, Commanding Officer, Aviation Supply Office, U. S. Navy Supply Corps), Project Management and Transportation, Distribution and Logistics. These short courses provide a valuable means of getting new PDRC developments to the potential users.

Facilities and Equipment

The Center has acquired a laboratory and a significant amount of computer equipment to aid in its research.

A Hewlett Packard model HP-1000 mini computer with a half dozen terminals is located in the laboratory. The Center also has direct multiplex communication to the Georgia Tech CYBER 170 computer for large algorithmic processing.

The equipment available at the PDRC includes two high resolution color graphics computers. The first is a Chromatics model CG 1999 which has 512 x 512 resolution and 48K Bytes of memory, dual 8 inch floppy disk drives, digitizer and light pen input. The second is a very powerful Chromatics model CGC 7900 which has 1024 x 1024 resoution, 128K Bytes of memory, dual 8 inch floppy disk drives, 10 megabyte hard disk, joy stick and light pen input.

The Center has also acquired an Apple III microcomputer with 128K bytes of memory and dual 5 inch floppy disk drives and three (3) IBM personal computers with 128K bytes of memory, dual 5 inch floppy disk drives and color graphics monitors.

New Research Initiatives

The existence and operation of the PDRC at Georgia Tech has stimulated two other major research activities: a two year $460,000 study for the Joint Deployment Agency and a Material Handling Research Center sponsored jointly by private industry and the National Science Foundation.

The Joint Deployment Agency (JDA) recently came to the PDRC seeking help with the design, development and implementation of models and algorithms for deployment planning. As a result of discussions, the PDRC has initated a major project to support JDA's efforts in this area.

The Joint Deployment Agency has reponsibility for planning and analysis for inter-agency aspects of the defense deployment function. The JDA also coordinates similar deployment planning/analysis functions within the various services - Army, Navy, Air Force and Marines. This effort requires the use of sophistocated methodology and a high degree of computer implementation.

The purpose of the PDRC effort is to examine the joint deployment planning function and suggest new methodology and computer methods for improving its effectiveness. The Center will:

(1) develop an understanding of the joint deployment functions; its objectives, constraints, models and methods,

(2) identify new methodology and computer methods which have high likelihood of application and improvement in the joint deployment function.

(3) conduct detailed analyses of the applicability of this methodology in the joint deployment function, and

(4) suggest specific methodologies and computer methods which should be incorporated into the joint deployment function.

The study is planned for two years duration with a budget of $460,686.

The Bethlehem Steel Corporation has contributed $10,000 in each of the last two years to purchase equipment and support faculty and student involvement in the Center. An additional $10,000 contribution has been received for the coming year. Several projects have demonstrated the capability for transfer of results produced in the Center to problems faced by Bethlehem Steel. The two areas examined to date with Bethlehem Steel are dry bulk vessel scheduling and aggregate production scheduling via interactive color graphics.

A major result of this and other involvement of industry in the PDRC has been the creation of the Material Handling Research Center at Georgia Tech. To meet the material handling research needs of U. S. industry, the

National Science Foundation has selected Georgia Tech as the location for a University/Industry Cooperative Research Center focusing on Material Handling. A planning grant has been awarded by the National Science Foundation to prepare for the University/Industry Material Handling Research center.

The award of the planning grant serves as recognition of Georgia Tech's current research emphasis and commitment to significantly broaden and expand research on material handling problems. Under the direction of Dr. John A. White, Professor of Industrial and Systems Engineering and members of PDRC, the Material Handling Research Center will conduct basic and applied research on material handling related issues with the ultimate goal of improving productivity in U. S. industry; at the same time, it will have as a major objective strengthening university/industry relationships.

The Material Handing Research Center will be supported financially by its member companies. Initially, some support will be provided by the National Science Foundation. However, the Center must be capable of becoming financially self-sufficient through its industrial membership. Toward this end, the research agenda for the Center will be established by its industry members.

V. RESEARCH CONTRIBUTIONS

Research areas receiving major emphasis during the first two years of the PDRC have been delivery system design, facility layout, design of unit load storage systems, design and operation of nonunit load storage systems, and scheduling. The development of human-aided optimization as a methodology for addressing most of the design problems has been given high priority. We shall briefly summarize the research accomplishments to date. A list of technical reports is given in Appendix A, along with brief abstracts of each.

Human Aided Optimization

The PDRC has devoted a major effort to continued development of research within the area of human-aided optimization. Researchers in the Center are addressing such questions as:

(1) Are some models more effective than others in their ability to support and enhance human involvement in the algorithmic solution process?

(2) What information can be derived from production/distribution models to present to the human?

(3) What information should the human provide to the computer?

(4) What principles can be derived that characterize the format and method of information exchange for human involvement? This includes color graphics displays, tabular information, light pens, joy sticks, etc.

(5) Are there optimum levels of human involvement? How much should/will the human do?

(6) Which functions (e.g., pattern processing) are more effective for the human component and which functions (e.g., number crunching) are best performed by computers?

(7) Are some production/distribution processes amenable to human-aided optimization while others are not? Can problem parameters be developed a priori which indicate that a human-aided optimization approach will prove effective?

Current interactive optimization research at the Center is concentrated in interactive routing, interactive facility design and interactive scheduling. The Center uses color graphics computer display terminals to encourage the introduction of human insight and experience into the fundamental models, methods and algorithms of operations research and industrial engineering. Researchers interface with the computer by calling up color coded spatial representations of problems as visual aids in the decision making process. Utilizing these aids, reseachers make intermediate decisions that guide the optimization procedures programmed in the computer. Routing problems are represented in transportation network displays; scheduling solutions are approached through immediately adjustable bar charts; and layouts are designed and shaped on color graphic floor plan displays.

Models and algorithms are continually being developed which permit the human/computer system to develop solutions in all of these areas. The tremendous advantage of the kind of system and philosophy active at the Center is that the color graphics display is open to immediate modification by direct human input and instant analysis of the effects of human choices is displayed. Modification of solutions and models continues until the operator and the computer have arrived at some acceptable approximation of optimality.

Research Reports 82-02, 82-15, 82-19, and 82-20 discuss specific design problems which have been addressed using human aided optimization systems. Other human aided optimization systems to address designing delivery systems with time windows, designing facilities with material movement along a tree structure, and long range scheduling of ships are currently in various stages of development.

Delivery System Design

Interactive optimization in delivery system design has been a continued interest within the center. Several research efforts have involved routing. PDRC Reports 81-04, 81-10 and 82-07 considered the travelling salesman problem and its application in distribution system modeling and analysis. Reports 82-15 and 82-20 discuss interactive optimization models and algorithms in delivery systems design.

In PDRC Reports 81-04 and 82-07, the travelling salesman problem is examined and new heuristics are presented for its solution. PDRC Report 82-07 presents a simple, yet elegant, travelling salesman heuristic based on sorting techniques of computer science. It is demonstrated that the algorithm is of order n log n and yields an average case bound of 1.25, (i.e., it generates solutions about 25% longer than optimal).

PDRC Report 81-10 presents a travelling salesman model for order-picking in a warehouse. It is shown that for certain warehouse configurations a "ladder" graph results. In this case the travelling salesman solution can be obtained in linear time in the number of aisles plus items.

The delivery problem has been the subject of much research in the Center. PDRC Report 82-15 documents a computer model which employs human-aided optimization to obtain high quality solutions for the case of a single distribution center delivering items to a number of customers. This third-generation development model generates solutions, equaling or exceeding the best ones known, to all of the standard test problems. The interactive optimization model is resident on a high quality color graphics computer interfacing with a CDC Cyber 170.

PDRC Report 82-20 discusses the roles of fixed and variable routes in delivery systems operation. Fixed routes are those which remain stable over extended periods of time (e.g., one quarter or one year). Variable routes are continually changing, and do not guarantee the same route for each new visit to a customer. The research showed that while a system discipline of variable routes tends to give slightly better quality (lower total distance travelled) solutions, it has the detrimental effect of increasing the need for buffer inventory to protect against stock-outs. Also, this burden of buffer inventory is shifted to the customer.

Research on the pick up and delivery problem has addressed the development of (1) models, (2) exact algorithms and (3) heuristic methods. PDRC Report 82-21 presents a heuristic method for the pick up and delivery problem which is based on the insertion technique. This heuristic has been coded on the Cyber 170 and tested on several sets of randomized data. It has also been applied to historical data supplied by the Navy Supply Center (NSC) in Charleston, South Carolina. Thus far, results with the heuristic appear favorable; it was able to improve by 11.8% on a previous computer solution to the NSC-Charleston data.

Another system is currently under development to address routing problems with time windows. This system also utilizes a color graphics interface together with a network flow model to help generate solutions. This work will be reported in the near future.

Some innovative new approaches to develop approximate solutions to the travelling salesman problem are discussed in Reports 81-04 and 82-07. These developments will ultimately be used to support the interactive routing system.

Computer Aided Facility Layout

A fundamental problem in the design of production systems is the physical arrangement, or layout, of facilities. Over the past twenty years, a substantial amount of research has been focused, directly or indirectly on the development of computer aids for solving facility layout problems. Despite the magnitude of earlier efforts, this remains a vital research topic for several reasons.

First, almost all previous research on computer aided layout has been "batch oriented," thus has ignored the possibilities for interactive graphics or human aided optimization. The widely available computer aided layout programs are for the most part, based on the quadratic assignment problem as the underlying model.

Second, the implementation technology for computer aided layout problems has not advanced much beyond the original programs of the mid-sixties. This is in sharp contrast to other problem solving techniques, such as network flow analysis, where advances in computational techniques have provided a breakthrough in problem solving capabilities.

Third, research in facility layout has not addressed the difficult problem of criterion definition. It is well known that the traditional closeness rating schemes are invalid from a utility theory perspective. Moreover, while everyone recognizes the multiattribute nature of the layout problem, research continues to consider only single attribute models.

Finally, research in facility layouts has focused on a static version of the problem. The problem of designing an evolving facility can at present only be addressed by ad hoc methods using static models.

The Center has an active research program addressing a number of important issues in computer aided facility layout. In PDRC Report 82-11 the most popular computer aided layout programs are given a critical appraisal. These programs permit no human interaction, ignore the issue of multiple criteria, and in general use crude computer implementation technology.

Explicit consideration of multiple criteria in the facility layout problem is addressed in PDRC Report 82-11. The methodology developed in this paper is based on the concept of two types of attributes: <u>intrinsic attributes</u> such as temperature, noise level, etc., which are based on the geographic location of an activity as well as the specific activities which are adjacent; and <u>flow attributes</u>, such as trips per hour, which relate two activities and are affected by the distance between them.

The two types of attributes are aggregated using the composite criterion model of Srinivasan and Shocker (<u>Psychometrika</u>, Vol. 38, pp.473-492, 1973) into a function of activity adjacencies and distances between activities. The aggregation procedure requires interrogation of the decision maker to elicit information that is used to estimate his utility or value function.

A computer package for determining the aggregation coefficients is described in PDRC Report 82-13. This is a general purpose software package, so it could be used for other applications of the composite criterion model.

A truly interactive system for block layout is discussed in PDRC Report 82-02. A matching model is employed to capture certain characteristics of the structure of a facility layout problem (e.g., strength of association, certain size and shape parameters). The solution to this model is then displayed on a color graphics terminal as a potential layout. Human input is utilized to account for constraints not represented in the matching model, and to guide the computer to a feasible layout. This interactive process is continued until some criterion of convergence is satisfied. This system is currently operational within the PDRC. Initial testing indicates that it is much superior to anything previously available.

Work is underway on a new system which tries to model "fixed route" characteristics of much of the modern material handling equipment. This approach is also interactive and utilizes the color graphics interface. However, it is based on an optimum cut-tree rather than a matching model.

Computer-aided facility layout research in the Center has begun to addressed the issue of multiple criteria in layout analysis. Work is continuing along this line, to refine the concept of attributes for layouts, and to develop more effective methods for incorporating the multiple attributes in the layout procedure.

In addition, several opportunities have been identified for developing new computer implementation technologies for facility layout programs. Ongoing work in this regard addresses data structures for representing and manipulating layouts, and relational data bases for layout analysis.

Unit Load Storage Design

The storage requirements for the U. S. Navy are significant. Land based storage systems have been observed at shipyards, supply centers, rework facilities, and general shore facilities. The storage methods observed can be roughly divided into conventional and automated storage. It can be further categorized as unit load versus non-unit load or small parts storage. Research has been performed at the PDRC in each of these areas.

Block stacking is used frequently at Naval Supply Centers for both food and paper items. Canned goods, such as soups and vegetables, as well as paper towels and office supplies, are usually stackable up to 3 or 4 tiers. The height of the stack is typically governed by load crushing characteristics, building height, or lift truck limits. Lane depths typically range from 2 to 3-deep to 20 to 25-deep. Such determinations are generally based on rules-of-thumb, intuition, and/or judgement. Little, if any, analysis has been used to determine the optimum lane depth. The essential tradeoffs involved in the block-stacking problem are as follows: the higher and deeper a storage lane the less aisle space per load stored; however, honeycomb loss increases with increased height and depth. Honeycomb loss occurs when empty storage slots exist in non-empty storage lanes; such slots cannot be used if stock rotation is to occur. The current state-of-the-art in research on block stacking is reviewed in PDRC Report 82-18.

PDRC Reports 81-09 and 82-18 describe analytical models that have been developed to aid in the design of block-stacking storage systems. The results of the research will not only improve the design of block stacking storage systems, but also will be relevant to the design of drive-in and drive-through rack systems and automated deep lane storage systems, such as

Litton's MOLE system, ACCO's REM system, and Interlake's SCATS system. Additionally, the consideration of honeycombing provides additional insights concerning the determination of the shelf height in an order picking system, and the design of case flow rack systems.

The basic assumptions of the research included a randomized storage policy; FIFO lot rotation; unit load storages and retrievals; no rewarehousing of stock; known lot sizes and known replenishment schedules.

The research concentrated on block stacking to illustrate the methodology used and issues considered in the analysis of unit load storage systems. Other storage methods investigated included single-deep pallet racks, double-deep pallet racks, and deep lane systems. Analytical models were developed and solution procedures were derived for a number of storage problems not previously addressed in the literature. Previous research in this area tends to be fragmented; hence, the research provided a unified body of knowledge related to the storage of unit loads using block stacking as a storage method.

Both single product and multiple product cases were analyzed. For a single product, the topics investigated included the withdrawal rate, bulk withdrawals, safety stock, lot splitting, space and handling costs, and economic lot size determinations for block stacking. For multiple products, the topics examined included aggregate space requirements, number of lane depths, replenishment schedules, and product assignments. A "real world" storage problem was used to demonstrate the application of the block stacking models. The methodology used in the joint determination of lane depths for multiple products was significantly different from previous treatments of the problem.

The models developed in the study can be used by warehouse planners to improve storage system dsign and operational decisions. Computational requirements for the algorithms are such that they can be implemented on microcomputers currently available.

Over the past years, interest in automated storage/retrieval (AS/R) systems has grown tremendously. Such systems have increased considerably in number and probably will continue to do so in the future. As noted in PDRC Report 82-06, the rapid growth in the interest in AS/RS systems can be attributed to such benefits as lower building and land cost, labor savings, reduced inventory level, and an improved throughput level, among others.

Much of the early work done to analyze AS/RS systems is based on simulation. Using simulation in designing such systems has the obvious drawback of added computational effort, plus the possibility of stopping with a badly suboptimum solution. The design variables for AS/RS systems typically can take on a wide range of values. Thus, simulating each feasible design long enough to assure steady-state behavior is expensive computationally and undesirable at an early design stage where the user is mainly interested in obtaining benchmark solutions.

In PDRC Report 82-04, closed-form expressions are developed to determine the expected travel time associated with each trip of the AS/RS machine based on single and dual command cycles. An immediate application of the travel time expressions is in designing AS/R systems and in measuring the performance of AS/RS installations.

Travel time models were developed for automated storage/retrieval machines under a number of randomized storage conditions. Results based on order statistics were used to determine expected travel times for both single and dual command cycles. Five alternative I/O locations were addressed. Four dwell point strategies for the AS/RS machine were considered. Based on the analyses performed, a number of insights were obtained concerning AS/RS design tradeoffs using the travel time models.

Among the important issues in the design of automated storage and retrieval systems is the assignment of materials to storage locations. Based on a combination of single command cycles and dual command cycles, the resulting assignment problem can be shown to be a quadratic assignment problem. As described in PDRC Report 82-19 interactive approaches have been used to solve the problem. A color graphics computer displays the assignment of products to storage locations using either a time scale or a distance scale. The designer may elect to interchange the locations of pairs of products or the computer will search for the best interchanges involving specified products.

Another approach to this problem is the work discussed in Report 81-13 regarding heuristics for the quadratic assignment problem. New quadratic assignment heuristics based on branch and bound have been designed and tested.

Nonunit Load Storage System Design and Operations

A number of alternatives exists for storing material in other than unit loads. This includes bin scheduling, miniload systems, carousel conveyors and flow racks. Picking mechanisms include pure manual, man-aboard machines, and computer controlled trucks and cranes. Despite the wide variation in equipment, many of the storing and picking problems have the same mathematical form.

PDRC 82-08 has implications for design of effective configurations when material movement is not in unit loads. A desirable configuration is to store items near each other if they are often part of the same order.

In general, sets of highly correlated items may be identified that should be stored together (e.g., in consecutive locations along a warehouse aisle). This would permit more efficient, cheaper, and faster retrieval of orders since the corresponding routing problems would have item locations highly clustered. Thus one natural problem is to store all items so that those highly correlated are "nearly" consecutive in the warehouse, along an aisle, on a shelf, on a carousel conveyor, etc. Alternatively, we may try to store correlated items so that as many items as possible are exactly consecutive. Both of these problems may be formulated as finding large, specially structured submatrices of a matrix with a row for each type of item, a column for each correlated set of items, and (i,j) = 1 if item type type i is in set j. PDRC Report 82-08 shows that this problem, for any network configuration of storage, is NP-complete and so "certifiably difficult." Thus the appropriateness of heuristics established. (Incidentally, PDRC Report 82-08 has quite far-ranging applications it establishes the difficulty of finding nice substructure in a host of matrix related problems. For example, a corollary is that a general method of effectively determining large exploitable substructure in integer programmi unlikely to exist.)

A problem in high volume, standardized warehousing is the coordination of periodic processes. For example, consider a single palletizer servicing several accumulation lanes with items arriving continuously. Each lane demands use of the palletizer periodically with known frequency. Demand may be postponed to service another, competing lane, but queueing space must be provided for items arriving in the deferred lane. PDRC Report 81-06 studies the synchronization of such periodic processes. It solves several versions of the 1-machine/2-job stream problem and then shows that the more general problem is probably unsusceptible to effective optimal solution. Moreover, to aid in the design of heuristics, the complexity of the problem is analyzed in detail.

To pick a single order from a warehouse, one must pick a collection of items. The best way to retrieve a collection of items includes a travelling salesman's tour of the storage locations of those items. Hence we are led to consider the travelling salesman problem within a warehouse. PDRC Report 81-04 emphasizes the need to take advantage of special structure in atacking this problem since it shows that, for the general problem, it is computationally infeasible to guarantee a tour within a factor of even n^n of optimal when retrieving n items.

PDRC Report 82-07 considers the special case of the planar travelling salesman and makes a significant contribution to this much-studied problem. It proposes a novel heuristic that is considerably faster (and easier to code) than any other commonly considered heuristic. It is based on sorting the inverse images of the points under a spacefilling mapping, and, since based on sorting, this heuristic tour may be accomplished in only nlogn steps. Thus the heuristic solution is quickly calculated and easily modified. This makes it particularly appropriate for microprocessor based control systems such as in modern AS/RS.

A very efficient solution procedure is developed in PDRC Report 81-10 for the order picking problem when the warehouse has crossover only at the ends of the aisles. This is one of the most common warehouse configurations. The computational effort for this procedure increases linearly in the number of aisles. The procedure has been successfully implemented on a personal computer. Even on these small computers, it is tractable for large warehouses.

Scheduling

The huge existing research literature on theory of scheduling seems to have had almost no effect on industrial scheduling practice. The Center's research program in this area is based on two guiding principles. The first is that new models of the problems must be developed to incorporate the complexities of real world planning and scheduling. This has resulted in a program to develop a theory of scheduling which explicitly accounts for the stochastic nature of the problems. PDRC Reports 81-02, 81-03, 81-05, 81-08, 81-14, 82-05 and 82-09 deal with traditional scheduling problems but under the assumption that processing times are stochastic. PDRC Reports 81-07, 81-11, and 81-12 survey the state-of-the-art in stochastic scheduling and analyze the complexity of these problems. This series of technical reports comprises the seminal work in stochastic scheduling.

The second principle is that the solution technique must ultimately be made useful to the practitioners. Scheduling techniques based on precedence networks first appeared in the literature over twenty years ago. The first simple methods were soon generalized to incorporate some notions of resource availability. There followed a tremendous number of research papers on algorithms for solving these project scheduling problems with resource considerations. If one looks, however, at large scale projects, (e.g., shipbuilding, submarine overhaul or nuclear power plant construction), one finds that this research has had virtually no impact on the practice of project planning. Thus, this remains a viable subject for a properly oriented research effort.

Research now being conducted on this topic within the Center departs in several ways from the mainstream of work appearing in the past decade. For example, PDRC Report 82-16 examines four classical problems and analyses the reasons why they have not been widely adopted and used in practice. Four new research issues are defined, based on extensive interaction with planners in shipyards. These new problems are better representations of the types of problems that occur in practice.

As an example of this approach, a model is developed in PDRC Report 82-17 for a problem in which there are alternative definitions for some activities. The context from which this model evolved was one of outfit planning in new ship construction. The basic concept behind this new model is to make the network synthesis a part of the decision process rather than simply a given for the analysis.

A solution procedure has been developed for this new model and has been evaluated on some realistic but randomly generated problems, with good results. The technical report describing the solution methodology is currently being condensed for publication.

Another branch of the research effort in this area has explored the development of interactive problem solution methods. A prototype interactive program has been developed for the HP1000 minicomputer and has been used in the Project Management short course. Experiments with this interactive program lead to the development of a new class of heuristics for the classical resource constrained CPM problems. A report describing these "delay regret" heuristics is in preparation.

The development of interactive solution techniques depends heavily on efficient storage and manipulation of the problem data. Project work to date has resulted in the identification of an efficient set of data structures and associated algorithms for basic calculations. While not a primary focus of the research, development of new implementation technology will continue.

Future work in this area will continue to address the issues reviewed in PDRC Report 82-16: technologies (such as group technology) for activity definition and network synthesis; more realistic resource models, (e.g., life cycle type availability curves; and techniques for accommodating the imprecise nature of the information available in the early stages of project planning.

VI. SUMMARY

There is a tremendous potential for research contributions in production and distribution. Most of the problems are very difficult both in terms of precise definition and solution. However, this only serves to increase their importance as research topics.

The main focus of the research effort should be on expanding our understanding of the problems associated with the processes of design and operation of production and distribution systems and on the development of new methodologies which can be used to improve these processes. This does not mean that we should stop developing new mathematical models and methodology. We simply need to develop the models based on a thorough knowledge of the problems that <u>need</u> to be solved rather than on the basis of what <u>can</u> be solved.

The research will require a continued interaction with practitioners who must actually solve the problems. It will also require a very significant time commitment. However, there is no reasonable alternative if we seriously wish to impact the state-of-the-art in production and distribution.

APPENDIX A

REPORTS TO DATE

PDRC Report Series

81-01 "Engineering/Production Integration Workshop," L. F. McGinnis

This discussion paper has developed from conversations and presentations at the Production/Integration Workshop sponsored by MarAd and held in Atlanta, Georgia, January 19-21, 1981, as well as contacts with a number of individuals in several U. S. shipyards. The paper addresses the general problems of U. S. shipbuilding productivity, their symptoms, and some programs designed to remedy these problems. The opinions expressed are the author's and not necessarily endorsed either by MarAd or the Office of Naval Research.

81-02 "Minimizing the Expected Makespan in Stochastic Flowshops," M. L. Pinedo.

The optimization problem of minimizing the completion time in flowshop scheduling is considered. Models with and without intermediate storage are considered. The processing times are stochastic. Solutions for special cases are found and based on these results, a more general rule of thumb is obtained.

81-03 "On the Optimal Order of Stations in Tandem Queues," M. L. Pinedo

Consider m nonidentical service stations which have to be set up in a sequence $j_1, j_2, \ldots, j_m$. At time $t = 0$ the system is empty and there is an infinite number of customers waiting in front of station j_1. Customers have to be served first at station j_1, after finishing service there they have to go through station j_2, etc. Both the cases of infinite waiting room and of zero waiting room between the stations are considered; in the case of zero waiting room, blocking may occur. We study how the output process depends on the sequence in which the stations are set up.

81-04 "A Note on Approximate Solutions to the Traveling Salesman Problem," J. J. Bartholdi, III.

An argument of Sahni and Gonzalez is strengthened to show that it is NP-complete to solve the symmetric, non-euclidean traveling salesman problem to within a factor of even n^n.

81-05 "Minimizing Expected Makespan in Stochastic Open Shops," M. L. Pinedo and S. M. Ross

Suppose that two machines are available to process n tasks. Each task has to be processed on both machines, the order in which this happens being immaterial. Task j has to be processed on machine 1 (2) for random time $X_j(Y_j)$ with distribution $F_j(G_j)$. This kind of model is usually called an Open Shop. The time that it takes to process all tasks is normally called the makespan. Every time a machine finishes processing a task a decision-maker has to decide which task to process next. Assuming that Xj and Y_j have the same exponential distribution we show that the optimal policy instructs the decision-maker, whenever a machine is freed, to start processing the task with longest expected processing time among the tasks still to be processed on both machines. If all tasks have been processed at least once, it does not matter what the deicision-maker does, as long as he keeps the machines busy. We then consider the case of n identical tasks and two machines with different speeds. The time it takes machine 1 (2) to process a task has distribution H_1 and H_2 are assumed to be New Better than Used (NBU) and we show that the decision-maker minimizes the expected makespan in a class of non-preemptive policies when he always gives priority to those tasks which have not yet received processing on either machine.

81-06 "Periodic Scheduling to Minimize Maximum Delay," J. J. Bartholdi, III and A. S. Rosenthal

We minimize delay costs for two continuous or periodic, non-preemptible job streams served by a single processor. For streams with two jobs we characterize zero-delay schedules and "simple-delay" schedules. Tight bounds are obtained for arbitrary schedules. The problem of n streams is shown to be NP-complete in the strong sense.

81-07 "Comparisons Between Deterministic and Stochastic Scheduling Problems with Release Dates and Due Dates," M. L. Pinedo

In this paper we consider stochastic scheduling models where the processing times of the jobs are independent exponentially distributed random variables. We consider release dates and due dates with arbitrary distributions. We show that these stochastic scheduling models with release dates and due dates have a very nice structure, while their deterministic counterparts cannot be solved in polynomial time.

81-08 "A Comparison Between Tandem Queues with Dependent and Independent Service Times," M. L. Pinedo and R. W. Wolff

This paper considers tandem queues in which a given customer has equal service times at each station. The case $M/M/1 \rightarrow M/1$ is considered in detail and the expected waiting time in the case where any given customer has independent service times at the two stations is compared with the expected waiting time in the case where any given customer has equal service times at the two stations. This comparison is based on theoretical results as well as on simulation. Tandem queues with blocking (zero queue capacity between the stations) are also considered and the waiting time and system capacity in the case where any given customer has independent service times are compared with the waiting time and systems capacity in the case where any given customer has equal service times.

81-09 "Storage System Optimization," J. O. Matson and J. A. White

This report focuses on optimization procedures for the design and evaluation of storage system alternatives, including block stacking, single-deep and double-deep pallet rack, and deep lane storage. The development and application of analytical models are demonstrated for the design of storage systems based on floor space utilization and handling time criteria.

81-10 "Order-Picking in a Rectangular Warehouse: A Solvable Case of the Traveling Salesman Problem," H. D. Ratliff and A. S. Rosenthal

This paper addresses the problem of order-picking in a rectangular warehouse where there are crossovers only at the ends of aisles. An algorithm is presented for picking an order in minimum time. The computational effort required is linear in the number of aisles. The procedure has been implemented on a micro computer. A 50 aisle problem requires only about 1 minute to solve.

81-11 "On the Computational Complexity of Stochastic Scheduling Problems," M. Pinedo

In this paper we consider stochastic scheduling models where all relevant data (like processing times, release dates, due dates, etc.) are independent random variables, exponentially distributed. We are interested in the computational complexity of determining optimal policies for these stochastic scheduling models. We give a number of examples of models in which the optimal policies can be determined by polynomial time algorithms while the deterministic counterparts of these models are NP-complete. We also give some examples of stochastic scheduling models for which there exists no polynomial time algorithm if $P \neq NP$.

81-12 "Stochastic Shop Scheduling: A Survey," M. L. Pinedo

In this paper a survey is made of some of the recent results in stochastic shop scheduing. The models dealt with include:

(i) Open shops.

(ii) Flow shops with inifinite intermediate storage permutation flow shops.

(iii) Flow shops with zero intermediate storage and blocking.

(iv) Job shops.

Two objectives functions are considered: Minimization of the expected completion time of the last job, the so-called makespan and minimization of the sum of the expectd completion times of all jobs, the so-called flow time. The decision-maker is not allowed to preempt. The shop models with two machines and exponentially distributed processing times usually turn out to have a very nice structure. Shop models with more than two machines are considerably harder.

81-13 "A Branch and Bound Based Heuristic for Solving the Quadratic Assignment Problem," M. S. Bazaraa and O. Kirca

In this paper a branch and bound algorithm is proposed for solving the quadratic assignment problem. Using symmetric properties of the problem, the algorithm eliminates "mirror image" branches, thus reducing the search effort. Several routines that transform the procedure into an efficient heuristic are also implemented. These include certain 2-way and 4-way exchanges, selective branching rules, and the use of variable upper bounding techniques for enhancing the speed of fathoming.

The computational results are quite encouraging. As an exact scheme, the algorithm solved the 12 facility problem of Nugent et al and the 19 facility problem of Elshafei. More importantly, as a heuristic, the procedure produced the best known solutions for all well-known problems in the literature, and produced improved solutions in several cases.

82-01 "Applications of Duality and Stochastic Dominance in Reliability Theory," M. L. Pinedo

In this paper we discuss a notion which is the dual of the failure rate and is defined as $f(t)/F(t)$. This concept has come up several times in the literature, but has never been investigated in detail. In this paper the name *survival rate* is used. We show that in many models of practical interest the survival rates of certain random variables have nice properties. This makes it possible to obtain bounds on the distribution functions of these random variables. Moreover, we show that a form of stochastic dominance based on the survival rates of the random variables has some interesting applications.

82-02 "Matching Based Interactive Facility Layout," B. Montreuil, H. D. Ratliff and M. Goetschalckx

A system is discussed for for interactively generating a block lay out for a facility. The system has three fundamental components: an optimization model (matching) which generates basic configuration, a colorgraphics display which allows prospective layouts to be displayed and manipulated, and a human decision maker who imposes constraints on the optimization model and directs the layout construction.

82-03 "Optimum Four Module Pallet Packing," H. D. Ratliff and T. Tran

A fundamental packing problem is to determine a pattern which maximizes the number of boxes of a given size which can be placed on a pallet. As a practical matter the pattern must be simple enough to be easily packed. For a particular class of such patterns, a procedure is presented which effectively finds the optimum. The procedure is implementable on a desktop computer and on average procedure patterns better than those in general use.

82-04 "Material Handling: A Review," J. O. Matson and J. A. White

A number of material handling research areas are reviewed and opportunities for further research are identified. Included in the review is a consideration of the following areas: robotics, conveyor theory, transfer lines, flexible manufacturing systems, equipment selection, storage alternatives, automated storage and retrieval systems, warehouse layout, palletizing, and order picking and order picing and accumulation.

82-05 "On Flow Time and Due Dates in Stochastic Open Shops," M. L. Pinedo

In this paper we consider Open Shops where the jobs have exponentially distributed processing times. We determine the policies that in the class of preemptive policies minimize the expected Flow Time. We also consider Open Shops where the jobs have random due dates. Under certain conditions we determine the policies that maximize the expected number of jobs that complete their processing before their respective due dates.

82-06 "Travel Time Models for Automated Storage/Retrieval Systems," Y. A Bozer and J. A. White

Travel time models are developed for automated storage/retrieval (AS/R) machines. The S/R machine travels simultaneously horizontally and vertically as it moves along a storage aisle. For randomized storage conditions expected travel times are determined for both single and dual command cycles. Alternative input/output (I/O) locations are considered. Additionally, various dwell point strategies for the storage/retrieval machine are examined.

82-07 "An O(NlogN) Planar Travelling Salesman Heuristic Based on Spacefilling Curves," L. K. Platzman and J. J. Bartholdi, III

N points in a square of area A may be sorted according to their images under a spacefilling mapping to give a tour of length at most 2 NA. If the points are statistically independent under a smooth distribution, with N large, then the tour will be roughly 25% longer than optimum (and a simple enhancement reduces this to 15%). The algorithm is easily coded: a complete BASIC program is included in the appendix. Since the algorithm consists essentially of sorting, points are easily added or removed. Our methods may also be used with simple dynamic programming to solve TSP path problems.

82-08 "A Good Submatrix is Hard to Find," J. J. Bartholdi, III

Given a martix, it is NP-hard to find a "large" submatrix that satisfies property , where is nontrivial, holds for permutation matrices, and is hereditary on submatrices. Such properties include *totally unimodular, transformable to a network matrix, permutable to consecutive ones,* and many others. Similar results hold for properties such as *positive definite, of bandwidth* $\leq w$.

82-09 "Stochastic Shop Models with Jobs that Have Dependent Processing Times at the Various Machines," M. L. Pinedo

In this paper we consider stochastic flowshops, job shops and open shops. Each machine has to perform on job j an amount of work w_j where w_j, is a random variable with distribution F_j. Machine i operates on job j with a speed of S_{ij}. Speed S_{ij} is random with distribution G_i. The time job j occupies machine i is T_{ij} which equals $W_j \cdot S_{ij}$. We determine for a number of special cases the policies of the expected makespan.

82-10 "Optimal Lot-Sizing in Acyclic Multiperiod Production Systems," V. V. Rao and L. F. McGinnis

This paper presents constructive, network-based proofs for the Wagner-Whitin property and a generalized Nested Schedule property for optimal production schedules in acyclic hierarchical multiperiod production systems. Algorithms for obtaining schedules with these properties and described and illustrated with examples.

82-11 "Computer Aided Layout Programs: A Contemporary Appraisal," L. F. McGinnis

Widely available facility layout programs are discussed. The program logic, data required, scoring methods and limitations are evaluated for both construction and improvement programs. Implementation technology and other areas of improvement are discussed.

82-12 "Multi-Criterion Layout Evaluation: The Value Measurement Problem," R. J. Graves, L. F. McGinnis and R. Joneja

This paper addresses the problem of explicitly incorporating multiple criteria in the selection of a facility layout. The approach is based on the composite criterion model of Srinivasan and Shocker [8] and utilizes the concepts of intrinsic attributes, which are location-oriented, and flow attributes, which are interaction-oriented. A methodology is described in detail and illustrated by a small example.

82-13 "A Computer Package for the Composite Criterion Model," L. F. McGinnis and R. K. Runyan

This report describes a general purpose computer package for analysis of the composite criterion model of Srinivasan and Shocker (Psychometrika-Vol. 38, No. 4, p. 473). A standard format allows data for a wide range of applications to be analyzed using this package. The report describes the development of the package, including the data base and the FORTRAN codes for performing the analysis. The sample problem used by Srinivasan and Shocker is analyzed to demonstrate the package.

82-14 "The Factory of the Future," J. A. White

The factory of the future is examined from a material handling perspective. Opportunities and impediments for the Factory of the Future are addressed. Three major parameters in justifying factory automation are identified and assessed. Material handling objectives for the automated factory are listed. Key issues in stepping up to automation are discussed.

82-15 "IRG - Interactive Route Generator: A Narrative Description," F. H. Cullen, J. J. Jarvis and H. D. Ratliff

IRG is an interactive color graphics based prototype model for vehiclerouting. This paper discusses the basic concepts for the system and gives a general overview of its operation.

82-16 "Project Scheduling with Resource Considerations," L. F. McGinnis

A great deal of research in activity network based project resource management seems not to have found wide spread adoption. We briefly consider why this is true and pose some new research problems.

82-17 "The Outfit Planning Problem: Production Planning in Shipbuilding," R. J. Graves and L. F. McGinnis

Shipbuilding as currently practiced in U. S. commercial shipyards employs little quantitative modelling or analysis in production planning. This paper presents a brief discussion of the shipbuilding process and focuses on one major component which is referred to as outfitting. The outfit planning problem is described in detail and then formally modelled as a generalization of the resource constrained project scheduling problem. The value of the approach as well as barriers to its adoption are also discussed.

82-18 "The Analysis of Some Selected Unit Load Storage Alternatives," J. O. Matson and J. A. White

The focus of the research is the development of optimization procedures and techniques to aid warehouse planners in the design and evaluation of selected unit load storage systems. The basic assumptions of the research include a randomized storage policy; FIFO lot rotation; unit load storages and retrievals; no rewarehousing of stock; known lot sizes and known replenishment schedules.

The study concentrates on block stacking to illustrate the methodology used and issues considered in the analysis of unit load storage systems. Other storage methods investigated include single-deep pallet racks, double-deep pallet racks, and deep lane systems. Analytical models are developed and solution procedures are derived for a number of storage problems not previously addressed in the literature. Previous research in this area tends to be fragmented; hence, the study provides a unified body of knowledge related to the storage of unit loads using block stacking as a storage method.

Both the single product and multiple product cases are analyzed. For a single product, the topics investigated include the withdrawal rate, bulk withdrawals, safety stock, lot splitting, space and handling costs, and economic lot size determinations for block stacking. For multiple products, the topics examined include aggregate space requirements, number of lane depths, replenishment schedules, and product assignments. A "real world" storage problem is used to demonstrate the application of the block stacking models. The methodology used in the joint determination of lane depths for multiple products is significantly different from previous treatments of the problem.

The models developed in the study can be used by warehouse planners to improve storage system design and operational decisions. Computational requirements for the algorithms are such that they can be implemented on micro-computers currently available.

82-19 "The Interactive Design of AS/R Systems," J. S. Shieh and J. A. White

Not yet published.

82-20 "Service Level Consideration in Distribution," F. H. Cullen, E. Frautchi, J. J. Jarvis and H. D. Ratliff

Not yet published.

APPENDIX B

VISITS TO NAVY AND RELATED INSTALLATIONS

Panel SP-8 of the Ship Production Committee, January and June 1981, Dr. Leon F. McGinnis.

Discussed research and development.

NSC, Norfolk, February 1981, Dr. John A. White.

Presented a three day seminar on Material Handling.

Newport News Shipbuilding Company, March 1981, Dr. Leon F. McGinnis.

Discussed research on shipyard production and explored the feasibility of joint research efforts.

SURFLANT, Norfolk, March 1981, Drs. H. Donald Ratliff and Tom Varley.

Discussion of ongoing research in ship scheduling.

Capt. Phil McKnight

CDR Lee Pittman
Fleet Scheduler

Mr. Gary Lipsett
Science Advisor

NSC, Norfolk, March 1981, Drs. H. Donald Ratliff, John A. White, and Tom Varley.

Tour of facilities and discussion of activities.

Rear Admiral J. E. McKenna
Commanding Officer

CDR James Blaylock
Planning Department

NARF, Norfolk, March 1981, Drs. H. Donald Ratliff, John A. White, and Tom Varley.

Tour of facilities and discussion of activities.

Capt. Bill McClellan
Commanding Officer

Dr. A. Syed
Office of Advanced Technology

Mr. Bill Maxwell
Office of Advanced Technology

Mr. Dennis Bradshaw

SURFLANT, Norfolk, March 1981, Dr. H. Donald Ratliff.
Presented a brief to Admiral Johnson and his staff on the roll of color graphics in long-range fleet scheduling.

NSC, Oakland, April 1981, Dr. John A. White.
Presented a seminar on "Material Handling in the 80's" to approximately 60 middle to upper management personnel.

NARF, Alameda, April 1981, Drs. H. Donald Ratliff, John A. White, and Tom Varley.
Tour of facilities and discussion of activities.

Mr. Richard Cohen
Planning Department

NSC, San Diego, April 1981, Drs. H. Donald Ratliff, John A. White, and Tom Varley.
Tour of facilities and discussion of activities.

Capt. Philip F. McNall
Commanding Officer

Capt. Richard P. Leisenring
Executive Officer

CDR Tod Barnes
Storage Officer

LCDR Ben McGuire
Planning Department

Mr. Art Senhan
NISTARS Program

NARF, San Diego, April 1981, Drs. H. Donald Ratliff, John A. White, and Tom Varley.
Tour of facilities and discussion of activities.

Mr. David Richardson
ASKARS Program

ivision

Mare Island Shipyard, April 1981, Drs. H. Donald Ratliff, John A. White, and Tom Varley.
Tour of facilities and discussion of activities.

Capt. Ernest J. Scheyder
Shipyard Commander

Capt. John L. Sechler
Supply Officer

CDR Robert F. Zitzewitz
SEAMISTS Project Officer

Mr. D. Spell
Head, Scheduling Section

Mr. Roy G. Gergus
Head, Industrial Management

Mr. David Runge
Superintendent

Mr. Darrel G. Graves
SEAMISTS Project

Mr. Al Hobson
SEAMISTS Project

Mr. Marlin Forthun
Head, Production Control Branch

Mr. Bruce Balbin
Head, Scheduling Section

Mr. William E. Cussins
General Foreman

Mr. Max H. Church
General Foreman

Mr. Ole Olejniczak
Head, Materials Center Branch

LTJG Lionel Munoz
Material Officer

MAT OC4, June 1981, Dr. Leon F. McGinnis.
Discussed research needs within the Shipbuilding Technology Program.
Bill Holden

NAVSEC, June 1981, Dr. Leon F. McGinnis.
Discussed research in multi-criteria layout.

Mr. Craig Carlson
Ship Arrangements Branch

SURFLANT, Norfolk, June 1981, Dr. H. Donald Ratliff.
Brief Admiral Johnson on using color graphics in ship scheduling.

Naval Ship R & D Center, Corderock, July 1981, Drs. H. Donald Ratliff, John J. Jarvis, John A. White and Leon F. McGinnis.
Preview of PDRC Research Program.

William Merckel
FMSO

Richard McNertney
FMSO 9323

CDR R. A. Lippert
FMSO 93

R. B. McClure
NAVSUP 0526

CDR M. C. Hoyt
NAVSUP 052

Jim Smith
ONR

Vick Carew
NAVSUP 032

Herb Lieberman
NAVSUP 043

Myron Stern
NAVSUP 0421

Maury Zubkoff
DTNSRDC 1871

Ray Melton
DTNSRDC 1871

Perry Prive
DTNSRCD

Edward R. Eichelman
NAVSUP 0322B1

Sea-90, July 1981, Drs. H. Donald Ratliff, Leon F. McGinnis, and Tom Varley.
Reviewed a brief on the ship procurement program evaluation and discussed the problem area and approaches that SEA-90 might use.

Ship Production Committee Panel SP-8, Industrial Engineering, Pascagoula, Mississippi, October 28-29, 1981, Dr. Leon F. McGinnis.
Discussed research and development needs in shipbuilding.

Briefing to Defense Logistics Agency, November 20, 1981, Drs. Tom Varley, H. Donald Ratliff, and John White.

VADM E. A. Grinstead, SC, USN
DLA-Director

MG E. Bowers, USA
DLA-DD Deputy Director

BG C. F. Drenz, BG, USA
DLA-DD CAS Deputy Director, Contract Adm. Services

BG M. A. Johnson, Jr., USMC
DLA-O Supply Operations

J. F. Maclin
DLA-OD Supply Operations

Col. W. M. Hood, USAF
DLA-OWP Supply Operations

L. Tambellini
DLA-OWP Supply Operations

D. Gearing
DLA-OWP Supply Operations

CAPT. Bell, SC, USN
DLA-WI Installation Services & Environment Protection

G. Clark
DLA-L Plans, Policies and Programs

L. Yankosky
DLA-L Plans, Policies and Programs

L. Zamarra
DLA-L Plans, Policies and Programs

D. Zimmerman
DLA-L Plans, Policies and Programs

L. Kohler
DLA-OS Supply Operations

L. Derdevanis
DLA-OS Supply Operations

N. Ramirez
DLA-WH Installation Services and Environment Protection

H. Gavin
DLA-WH Installation Services and Environment Protection

C. Waters
Supply Operations

NARF, Norfolk, January 8, 1982, Dr. John A. White.
Briefed Capt. Billy L. McClellan on material handling state-of-the-art; provided consultation to them on their ASKARS Program and on NARF moderization opportunities.

NAVMAT Productivity Series, March 11, 1982, Dr. John A. White.
Presented a seminar for The Chief of Naval Material.

VADM E. B. Fowler
Commander
Naval Sea Systems Command

VADM. E. R. Seymour
Commander
Naval Air Systems Command

RADM L. R. Sarosdy
Assistant Commander of Logistics/Fleet Support
Naval Air Systems Command

RADM J. P. Jones
Vice Commander
Naval Facilities Engineering Commander

RADM J. W. Lisanby
Principal Deputy Commander for Acquisition
Naval Sea Systems Command

RADM A. D. Williams
Commander
Naval Aviation Logistics Center

RADM R. E. Curtis
Vice Commander
Naval Supply Systems Command

Ship Production Committee Panel SP-4, Design/Production Integration, Harley Hotel, Atlanta, Georgia, March 24-25, 1982, Dr. Leon F. McGinnis.
Discussed research needs in U. S. shipbuilding.

Joint Deployment Agency, McDill AFB, Florida, June 1982, Drs. John J. Jarvis and H. Donald Ratliff.
Discussed deployment modeling.

National Defense University, Armed Forces Staff College, Norfolk, Virginia, July 1982, Drs. John J. Jarvis and H. Donald Ratliff.
Attended JDS users conference on deployment modeling.

Military Traffic Management Command, Washington, D. C., July 1982, Drs. John J. Jarvis and H. Donald Ratliff.
Discussed MTMC's deployment models.

Military Sealift Command, Washington, D. C., July 1982, Drs. John J. Jarvis and H. Donald Ratliff.
Discussed MSC's deployment models.

Military Aiflift Command, Scott AFB, Illinois, July 1982, Drs. John J. Jarvis and H. Donald Ratliff.
Discussed MAC's deployment models.

Command and Control Technical Center, Washington, D. C., August 1982, Drs. John J. Jarvis and H. Donald Ratliff.
Discussed CCTC's deployment models.

Office of Secretary of Defense, Washington, D. C., August 1982, Drs. John J. Jarvis and H. Donald Ratliff.
Discussed deployment modeling.

APPENDIX C

PRESENTATIONS TO INDUSTRY AND AT NATIONAL MEETINGS

ORSA/TIMS Joint National Meeting, Washington, D. C., "Optimum Designs of Automated Storage/Retrieval Systems," Y. A. Bozer and J. A. White, May 1980.

SHARE Atlanta Meeting, "Interactive Optimization," F. H. Cullen, J. J. Jarvis and H. D. Ratliff, August 1980.

Human Aided Optimization Conference, Philadelphia, Interactive Routing," F. H. Cullen, J. J. Jarvis and H. D. Ratliff, August 1980.

Southeastern TIMS, Atlanta, "Interactive Routing," J. J. Jarvis, October 1980.

Computers and Industrial Engineering, Orlando, Interactive Layout Using Color Graphics," M. Goetschalckx, B. Montreuil and H. D. Ratliff, October 1980.

REAPS Technical Symposium, Philadelphia, " The Outfit Planning Problem: Production Planning in Shipbuilding," L. F. McGinnis, October 1980.

ORSA/Tims Joint National Meeting, Colorado Springs, "Multiobjective Optimization and Its Applicability to Layout Design," and "Determining Optimal Utilization Factors," L. F. McGinnis, November 1980.

ORSA/TIMS Joint National Meeting, Colorado Springs, "Interactive Optimization in Constrained Routing," F. H. Cullen, J. J. Jarvis and H. D. Ratliff, November 1980.

Southcon 1981 Conference, Atlanta, "Color Graphics and Interactive Optimization," J. J. Jarvis, January 1981.

IE Managers Seminar, AIIE, New Orleans, "Material Handling: Its Vital Role in the 80's," J. A. White, April 1981.

1981 National Material Handling Forum, Material Handling Institute, Chicago, "Reducing In-Process Inventories through Materials Management and Production Controls," J. A. White, April 1981.

1981 International Logistics Congress, San Francisco, "Strategic Planning for Material Handling," J. A. White, April 1981.

1981 International Logistics Congress, San Francisco, "Computer Aided Plant Layout," M. Goetschalckx, B. Montreuil and H. D. Ratliff, April 1981.

72nd Annual Meeting of the Steel Service Center Institute, Atlanta, Georgia, "Material Handling and the Bottom Line: Meeting the Service Requirements of the 80's," J. A. White, May 1981.

CORS/TIMS/ORSA, Toronto, "Learning and Interactive Routing," F. H. Cullen, J. J. Jarvis, and H. D. Ratliff, May 1981.

CORS/TIMS/ORSA, Toronto, "Modelling and Analysis of an Acyclic Multi-Stage Production Planning Problem," and "Multi-Criteria Layout Evaluation: The Value Measurement Problem," L. F. McGinnis, May 1981.

CORS/TIMS/ORSA, Toronto, "A Line-Balancing Heuristic Based on Bin-Packing," J. J. Bartholdi, III and H. D. Ratliff, May 1981.

Mobil Oil, New York, "Interactive Graphics Applications in Human Aided Optimization," J. J. Jarvis, June 1981.

NATO Advanced Study Research Institute on Deterministic and Stochastic Scheduing, Durham, England, "Stochastic Shop Scheduing: A Survey," and "On the Computational Complexity of Stochastic Scheduling," M. Pinedo, July 1981.

National Science Foundation Workshop on Modelling and Simulation on Manufacturing Systems, University of Michigan, J. A. White, July 1981.

National Science Foundatin Workshop, University of Michigan, Ann Arbor, Michigan, "Production and Distribution Research Needs," J. A. White, August 1981.

Graduate Seminar Linkoping Institute of Technology, Linkoping, Sweden, "Production and Distribution Research Results," J. A. White, September 1981.

Exxon Research, Florham Park, New Jersey, "Quantitative Methods in Physical Distribution Systems," M. Pinedo, September 1981.

Westinghouse Education Center, Pittsburgh, Pennsylvania, "Material Handling and Facilities Planning," J. A. White, September 1981 and February 1982.

4th International Conference on Automation in Warehouse, Tokyo, Japan, "Optimizing Storage System Selection," J. W. White, N. A. DeMars, and J. O. Matson, October 1981.

4th International Conference on Automation in Warehousing, Tokyo, Japan, J. A. White, N. A. DeMars, and J. O. Matson, October 1981.

ORSA/TIMS, Houston, Texas, "Interactive Fleet Scheduling," B. B. Brownlee, H. D. Ratliff, and B. K. Thorn, October 1981.

Farm Industry Equipment Institute Conference, Kansas City, Kansas, "Increasing Productivity in Warehousing," J. W. White, November 1981.

General Motors Annual Material Handling Productivity Conference, Keynote address, Detroit, Michigan, "Integrated Material Handling Systems and the Automated Factory," J. A. White, November 1981.

IIE/MHI Seminar, Santa Clara, California, "Technology of Systems Design," J. A. White, February 1982.

IIE/MHI Seminar, Santa Clara, California, "Material Handling Hardware Technology: A State-of-the-Art Review," J. A. White, February 1982.

IBM'S Manufacturing Technology Institute, New York, New York, "Integrated Material Handling Systems," J. A. White, March and April 1982.

Fourth National and First International Conference for Computers and Industrial Engineering, Orlando, Florida, "Multiproduct Production Allocation via Generalized Networks," L. F. McGinnis, March 1982.

Fourth IE Managers Seminar, Chicago, Illinois, "The Automated Factory and Integrated Systems in the 80's," J. A. White, March 17, 1982.

ORSA/TIMS National Meeting, Detroit, Michigan, "Comparisons Between the Deterministic and Stochastic Problems," M. L. Pinedo, April 1982.

ORSA/TIMS Joint National Meeting, Detroit, Michigan, "Modeling Automated Storage/Retrieval Systems," Y. A. Bozer, J. S. Shieh, and J. A. White, April 1982.

ORSA/TIMS Joint National Meeting, Detroit, "Service Level Considerations in Distribution," F. H. Cullen, J. J. Jarvis, and H. D. Ratliff, April 1982.

ORSA/TIMS Joint National Meeting, Detroit, "Modeling Automated Storage/Retrieval Systems," Y. A. Bozer, J. S. Shieh, and J. A. White, April 1982.

Long Island Forum on Technology Annual Conference, Long Island, New York, "The Factory of the Future," J. A. White, April 1982.

Productivity Improvement in Marine Cargo Handling, Joint Department of Transportation, Maritime Administration, IIE Conference, San Pedro, California, "Improving Productivity through the Planning and Integration of New Material Handling Technologies," J. A. White, April 1982.

Symposium on Industrial Engineering, Applications in the U. S. Shipbuilding Industry, New Orleans, LA, "A Method for Establishing Useful Time Standards for Production Planning and Control in Shipyards," L. F. McGinnis, May 1982.

AIIE Annual Conference, New Orleans, Louisiana, "Project Scheduling with Resource Considerations," L. F. McGinnis, May 1982.

Annual Conference International Material Management Society, Keynote Address, Atlanta, Georgia, J. A. White, June 1982.

EURO V/TIMS XXV Conference, Lausanne, Switzerland, "Analysis and Design of Storage Systems," J. O. Matson, J. S. Shieh, and J. A. White, July 1982.

EURO V/TIMS XXV Conference, Lausanne, Switzerland, "Order Picking Strategies," M. Goetschalckx and H. D. Ratliff, July 1982.

EURO V/TIMS XXV Conference, Lausanne, Switzerland, "Interactive Facility Systems Design," M. Goetschalckx, B. Montreuil, and H. D. Ratliff, July 1982.

APPENDIX D

VISITORS TO PDRC

VISITORS TO THE PDRC

Union Carbide - September 1980

Lyn Peacock

Texas Instruments - October 1980

Floyd Hollister

Tennessee Eastman - October 1980

Mark Lowe

Chinese Delegation - November 1980

General Motors - January 1981

Florida Power - January 1981

Gary Thomas

National Science Foundation - March 1981

Abe Haddad

Department of the Navy - March 1981

Captain Lynn Flach
Commanding Officer
Navy Supply Corp School
Athens, Georgia

Commander Doug Falconer
Executive Officer
Navy Supply Corp School
Athens, Georgia

Commander Dan Robinson
Director, Education
Navy Supply Corp School
Athens, Georgia

(Department of the Navy continued)

Lt. Commander Bob Gilbert
Instructor, Uniform Automated
Data Processing System
Navy Supply Corp School
Athens, Georgia

Commander Bob Grant
Planning Officer
Naval Supply Center
Oakland, California

Coca Cola - March 1981

P. E. Alvelda
Manager
Production Support Group - Americas
Corporate Production Services

H. Caceres
Assistant Director
Corporation Production Services

J. Kedzier
Engineer
Production Support Group - Europe and Africa
Corporate Production Services

E. F. Pearce
Engineer
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T. L. Sadosky
Consultant
Corporate Production Services

J. F. Walker
Manager
Production Management Services
Corporate Poduction Services

Harold Berkessel
Vice President
Market Development

Bill Butterfield
Manager
USA Distribution

(Coca Cola continued)

Mike Arpeo
Manager
Company Bottling
Operations - Distribution

Bob Foley
Manager
Merchandising and Distribution

Ed Kridakorn
Manager
Management Science

<u>Bell Laboratories</u> - April 1981

Ward Whitt

<u>Stroh Container</u> - April 1981

Walter Haught

<u>Westinghouse Corporation</u> - April 1981

Jerry Hudspeth
Vice President for Productivity

George Moore
Director of Education Department
and Executive Director of Westinghouse
Educational Foundation

Paul A. Ockerman
Director of Manufacturing
Industry Products Company

Howard Pierce
Director of Manufacturing
Power Systems Company

<u>United Technologies</u> - April 1981

Luis A. Chong
Director of Technical Planning

Oldsmobile Division of GMC - April 1981

David C. Schmidt
Senior Administrator of Salaried Personnel
Oldsmobile Division of GMC

Jim Rucker
Assistant Comptroller
Oldsmobile Division of GMC

The Boeing Company - May 1981

Dr. George A. Schairer
Former Vice Presient
Consultant

William A. Walls
Chief of Technical Staff
Vertol-Boeing

TRW - May 1981

George Lehocky

Federal-Mogul - May 1981

Gus Carlson

Union Camp - May 1981

Peter Mani

Ft. Gordon - May 1981

Gen. Hilsman

Alcoa - May 1981

Frank Cormia

Kurt Salman - May 1981

Cecil Phillips

German Delegation - May 1981

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Corning Glass Works - May 1981

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Transportation/Distribution/Logistics Modeling Short Course - May 1981

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The Standard Oil Company - June 1981

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L. G. Johnson (August)
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Bethlehem Steel Corporation - July 1981

K. L. Stott
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Johnson & Johnson Company - July 1981

Technical Analysis Corporation - August 1981

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<u>Armco, Inc.</u> - August 1981

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<u>Qubic</u> - August 1981

Joe Ravenis

<u>Mervyn's</u> - September 1981

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<u>Israel</u> - September 1981

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<u>National Linen Service</u> - September 1981

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Georgia Power Company - September 1981

Bob Cole
Transmission Data Supervisor

Glenn McFerren
SIS Project Leader (Substation Information System)

Department of the Navy - September 1981

LCDR George McLaughlin
LCDR George Carroll
LT Don Price
LT Bert Carrody
CWO3 Arthur Powers
CWO3 Richard Caldwell
LCDR Warren Lippett
LTJG R. V. Crlenjak

Tektronix - October 1981

Luke Donnelly
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Gerald E. Heppell, Ph.D.
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University of Montreal - October 1981

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Computer Graphics Group, Inc. - October 1981

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Mathematisch Centrum, Amsterdam - October 1981

Dr. Jan Karel Lenstra

Japan Management Association IE-Study-Team - November 1981

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(Japan Management Association IE-Study-Team continued)

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Ken'ichiro Higuchi
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Cornell University - November 1981

Professor William L. Maxwell
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National Advisory Board - November 1981

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Canadian National - November 1981

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Exxon Corporation - November 1981

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Hitachi, Ltd. - November 1981
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Sperry Univac, S.A. - November 1981

Jose M. Gomez Solaun
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American Hi-Tech Instruments, Inc. - December 1981

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National Research Council Canada - December 1981

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Texas Instruments, Inc. - December 1981

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MacDill Air Force Base - December 1981

S. W. Hall, Jr. (Woody)
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Georgia Power Company - January 1982

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Wang Laboratories Inc. - February 1982

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Robert Bosch Corporation - February 1982

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ARMCO National Supply Company - April 1982

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Rockwell International - February 1982

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Georgia Tech Research Institute - March 1982

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Cobb County Public Schools - April 1982

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NSF Workshop - May 1982

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